# Space Weather Technical Forecast

Issued on Saturday, 25 November 2023 at 13:28 Local

**This technical forecast provides a four day assessment of space weather events. The probabilities stated below are for reaching or exceeding the given levels. For more information about space weather impacts please see the Met Office Space Weather Scales https://www.metoffice.gov.uk/weather/learn-about/space-weather/uk-scales**

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**Space Weather Forecast Headline: Isolated M-class flares/R1-R2 Radio Blackouts likely throughout. Chance of G1 Geomagnetic Storms Days 1-2 (25-26 Nov).**

**Analysis of Space Weather Activity over past 24 hours**

**Solar Activity:** Solar activity has been Low, with a peak Long Duration Event (LDE) C5.5 flare at 24/2219 UTC from AR3490, part of the cluster of sunspot regions in the north centre disc. There are currently twelve sunspot groups on the visible disc, the majority of which are located in the eastern half of the disc. Near centre disc in the northern hemisphere there is a cluster of four sunspot groups that appear to be contained within the same area of plage and magnetically connected. AR3490 (Dac/Beta-Gamma) has recently seen the splitting and spreading of its largest spot leading to reclassification, this region also lost its delta configuration earlier Day 1 (25 Nov). AR3492 (Chi/Beta), the largest group within the region, consists of two larger unipolar spots and a trail of faint spots of opposite polarity that extend to the east, with the group weakly bipolar as a result. AR3502 (Dao/Beta) and AR3491 (Hsx/Alpha), to the south of this remain largely unchanged.

AR3500 (Dkc/Beta-Gamma-Delta), in the southeast, is the largest and most complex single region on the disc. This compact region consists of several spots, including one large delta spot in the central portion. AR3499 (Dai/Beta) in the southwest has seen some longitudinal growth and increase in complexity with the proliferation of a number of minor spots.
The other groups on the disc are smaller and more magnetically simple than the previously mentioned regions, this includes newly numbered AR3503 (Cso/Beta) close to the northeastern limb.

A CME associated with the M1.1 flare produced by AR3499 at 24/0933 UTC has been analysed and modelled as a likely miss below Earth's orbit, with just a slight chance of a glancing blow on Day 3 (27 Nov). The LDE C5 flare at 24/2219 UTC from AR3490 may have produced a CME, however, there is only a very faint signal on available coronagraph imagery so it is assumed that much of the associated ejecta has been reabsorbed. No further Earth-directed CMEs have been observed in the period.

**Solar Wind / Geomagnetic Activity:** Solar wind parameters, as measured by ACE and DSCOVR at L1 were indicative of a background solar wind regime following the easing of the connection to CH73/+. Wind speeds were initially around 340 km/s, but since 24/1900 UTC increased gradually to Slightly Elevated levels. Following a discontinuity around 24/2300 UTC wind speeds increased to 470 km/s, and saw a more significant jump and minor discontinuity around 25/0800 UTC to Elevated levels with speeds of 530-580 km/s. This enhancement is indicative of a CME arrival at L1 and has been attributed to the arrival of the filament eruption CME from 22 Nov. Solar wind density was generally below average, but increased to above average levels from around 24/2230 UTC, with a peak of 25ppcc at 25/0847 UTC. The IMF was predominantly at Weak levels but increased to Moderate around 24/2300 UTC. Since the CME arrival levels have been more persistently at Moderate with a brief peak of 18nT. The important north-south component (Bz) varied weakly at first. Later in the period, and more persistently since the CME arrival, the Bz has varied periodically and between +9/-16nT and since 25/0600

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UTC has predominantly remained strongly negative (southward oriented). Phi angle was mostly positive (away from the Sun), but since around 25/1100 UTC has been close to neutral. The resultant geomagnetic activity was initially Quiet (Kp 1-2), but increased to Unsettled (Kp3) from 24/1800 UTC and has been at Active levels since the 25/0600-0900 UTC interval.

**Energetic Particles / Solar Radiation:** GOES16 high energy (greater than 10MeV) proton flux remained at Background levels. GOES16 high energy (greater than 2MeV) electron flux was generally at Moderate levels, but peaked at High levels (1170pfu) very briefly at diurnal maximum (24/1415 UTC). Following the onset of disruption that preceded the CME arrival observed values returned to Background levels again. The associated 24-hour fluence has remained below the Active threshold (1e8 integrated pfu) on an increasing, then gradually declining trend. The fluence observation at 25/0000 UTC was 3.72e7 integrated pfu.

**Four-Day Space Weather Forecast Summary**

**Solar Activity:** Solar activity is expected to be Moderate with further isolated M-class flares (R1-R2, Minor-Moderate) likely and a slight chance of an isolated X-class (R3-Strong) flare. The main flare risk is from regions currently positioned on the eastern solar hemisphere and those in the cluster close to the centre of the disc in the north. Despite this, the recent M1.1 flare originated from the relatively magnetically simple area in the southwest.

**Solar Wind / Geomagnetic Activity:** Two further CMEs feature in the forecast period, with effects from a recent arrival expected to wane through Day 1 (25 Nov). A filament eruption CME observed from late 22 Nov is forecast to arriving either late Day 1, or more likely early Day 2 (26 Nov). A further CME resulting from the M1.1 flare from AR3499 on 24 Nov has been analysed and modelled as a likely miss, with just a slight chance of a glancing blow on Day 3 (27 Nov).
Solar winds are currently enhanced following the recent CME arrival and are at Elevated levels, around 550 km/s. Speeds may erratically decline to (or close to) Slightly Elevated levels later Day 1 as enhancement wanes. Further CME enhancement is anticipated on Day 2 (26 Nov), with more persistently Slightly Elevated speeds expected. The next significant coronal hole enhancement is expected to arrive through Day 2 (26 Nov) with the arrival of a HSS from CH75/+, giving speeds of 500-550 km/s (Elevated) that should broadly persist until the end of the forecast period.

Geomagnetic activity is expected to be initially Unsettled (Kp 3). Upon arrival of a CME late Day 1 (25 Nov) or early Day 2 (26 Nov) Active to G1/Minor Storm (Kp 4-5) conditions are probable. Combined CME and HSS influences may extend slightly enhanced Geomagnetic activity at Quiet to Unsettled levels (Kp 1-3) into Day 3 (27 Nov), but should subside to become mainly Quiet (Kp 0-2) Day 4 (28 Nov).

**Energetic Particles / Solar Radiation:** GOES16 high energy proton flux is expected to remain at Background levels. However, there is a slightly higher risk of observing S1/Minor Storm conditions compared to normal, given the number of sunspots currently on the disc and their propensity to move into a more favourable location on the disc for connection with Earth in the coming days.

Electron flux levels have recently fallen to Background levels following the arrival of the CME from early 22 Nov. Similarly suppressed flux levels are expected over the coming days given forecast combined CME and high-speed stream influence on Geomagnetic activity. High levels of election flux are unlikely to be reached until day 4 (27 Nov) when there is an increasing chance that the reduction in the solar wind pressure following the CMEs and high-speed streams could allow electron flux to subsequently increase.
Fluence levels are expected to remain below the 1e8 Active threshold throughout the period with any notable rise not expected to take place until day 4 (28 Nov) or later.

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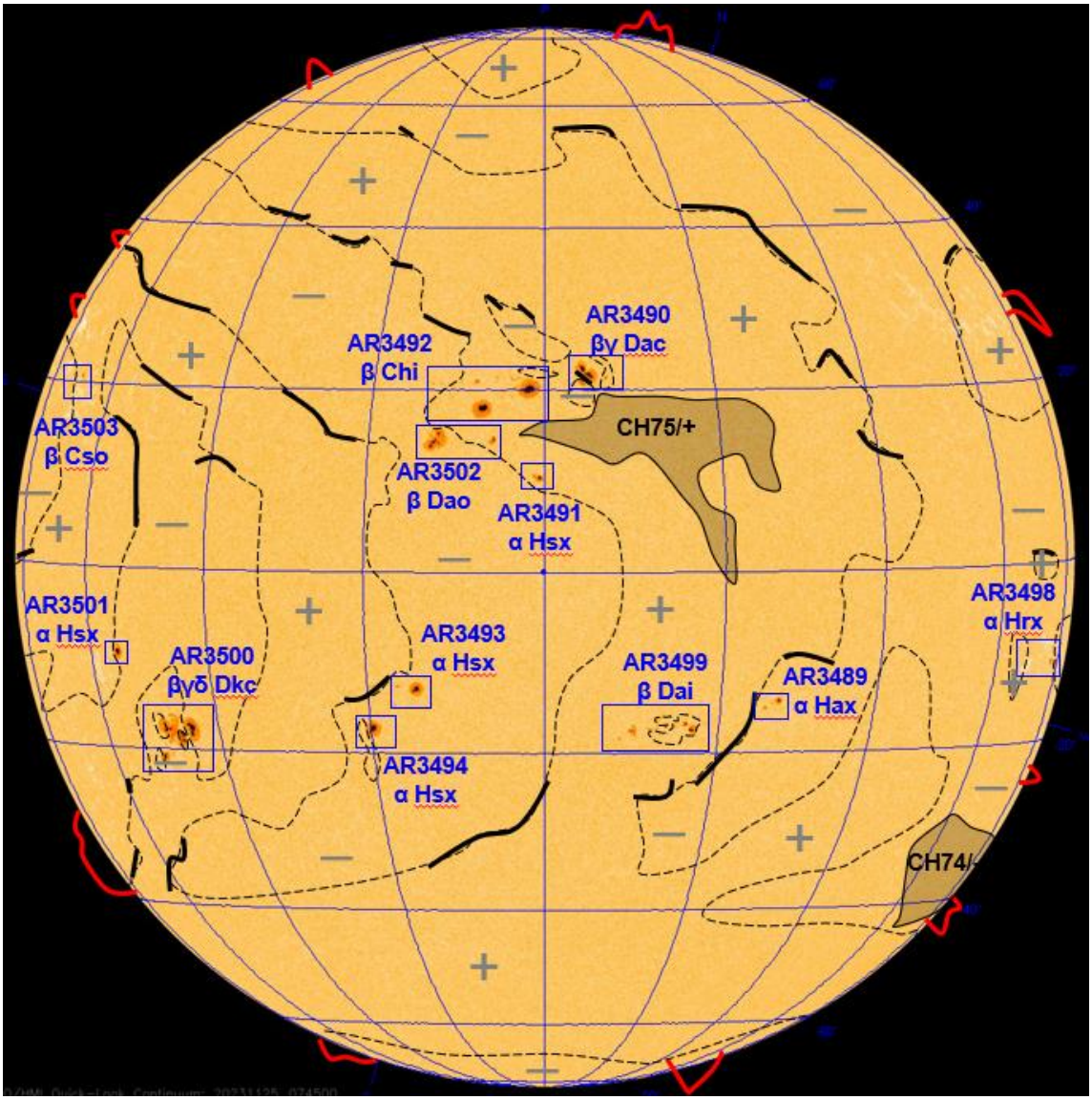
**Figure 1. Solar Analysis Valid 25/0800 UTC.**




**Key:** Filament ___ , Prominence ___ , Magnetic Field Line - - - , Polarity +/-, Coronal Holes: Grey shaded area CHxx +/-, Sunspot groups 25xx - Mt Wilson α-β-βγ-βγδ and Zurich-McIntosh Axx etc.

## Geomagnetic Storms:

Although CMEs have been observed on coronagraph imagery leaving the Sun over the past 24 hours, confidence is high that these do not have Earth-directed components.

Three Earth-directed CMEs feature in the forecast. The first is from a filament eruption in the southeastern quadrant early on 22 Nov which is considered to have arrived earlier on Day 1 (25 Nov), matching with Enlil modelling and the projected arrival time of this feature. A second, partial halo, CME was evident on LASCO and STEREO imagery from 22/2100 UTC directed mainly southwards. A coronal dimming spanning several hours preceded this appearance on LASCO imagery, starting around 22/1930 UTC in the vicinity of AR3489 and accompanied by two flare ribbons, indicative of post-eruptive magnetic re-connections in the Sun's corona following a filament eruption. Confidence is moderate that these observations are related, and for a CME arrival at Earth from this filament eruption around 26/0000 UTC or during the UTC

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morning of Day 2 (26 Nov), although only moderate confidence in timing. The final CME in the forecast is associated with the 24/0933 UTC M1.1 flare from AR3499 in the southwest disc; this has been analysed and modelled as a likely miss below Earth's orbit with just a slight chance of a glancing blow on Day 3 (27 Nov).

Solar winds are currently at Elevated levels around 540 km/s having increased from around 340 km/s at the start of the period following the recent CME arrival. Speeds may fall erratically during the remainder of Day 1, returning to Slightly Elevated levels as enhancement from the CME. Speeds are likely to increase into Day 2 following the arrival of a second CME. The onset of a HSS from CH75/+ is anticipated later Day 2. On the previous rotation, this coronal hole was a much larger and darker feature than it appears currently on coronagraph imager and resulted in speeds of 570 km/s and a period of several days at Elevated levels. On this rotation, speeds of 500-550 km/s are expected with uncertainty derived from the timing and potential coincidence of enhancement from the CME arrival and HSS onset on Day 2.

Geomagnetic activity is currently Active (Kp 4), and is expected to reduce to mainly Unsettled levels ahead of the next CME arrival either late Day 1 (25 Nov) or more likely early Day 2 (26 Nov) when further Active to G1/Minor Storm (Kp 4-5) conditions are probable. Geomagnetic activity on the previous rotation was Kp 3-5 (Unsettled to G1/Minor Storm) associated with the HSS from CH66/+. Similar, or slightly muted, enhancement is expected to take place upon connection to the CH75/+ HSS. Should the arrival of the HSS overlap with the anticipated effects of the late 22 Nov CME, enhancement may be initially masked. Combined CME and HSS influences may extend a period of somewhat enhanced Geomagnetic into Day 3 (27 Nov), with Quiet to Unsettled levels (Kp 1-3) but should subside to become mostly Quiet (Kp 0-2) by Day 4 (28 Nov).

| Geo-Magnetic Storm Probability (Exceedance) | Level | Past 24 Hours (Yes/No) | Day 1 (00-24 UTC) (%) | Day 2 (00-24 UTC) (%) | Day 3 (00-24 UTC) (%) | Day 4 (00-24 UTC) (%) |
|---|---|---|---|---|---|---|
| Minor or Moderate | G1 to G2 | No | 50 | 50 | 10 | 1 |
| Strong | G3 | No | 5 | 5 | 1 | 1 |
| Severe | G4 | No | 1 | 1 | 1 | 1 |
| Extreme | G5 | No | 1 | 1 | 1 | 1 |

## Geomagnetic Activity - Earthbound Coronal Mass Ejections

| Date/time 21.5R (UTC) | Halo: Full or Partial | Source | Source Location | Estimated Speed | Estimated Arrival Time | Comments |
|---|---|---|---|---|---|---|
| 22/1241 | Partial | Filament Eruption | SE | 760 km/s | 25/0000 UTC | Arrived at L1 from 24/2300 UTC. |
| 23/0535 | Partial | Filament Eruption | SE (near AR3489) | 540 km/s | 26/0000 UTC | Moderate / High confidence in arrival time. |
| 24/1707 | Partial | Filament Eruption | S central disc | 522 km/s | 27/1500 UTC | Slight chance of glancing blow. |

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**Figure 2: SDO/AIA-211 imagery showing the difference in position and strength of coronal holes between last rotation (left) and this rotation (right)**

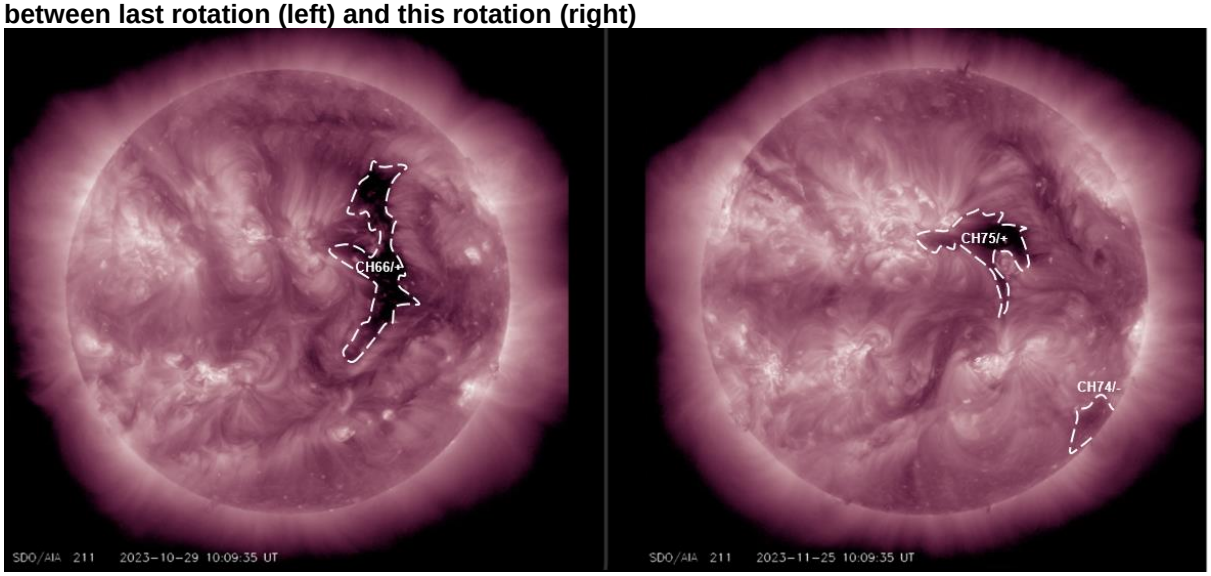



**Figure 3: MOSWOC REFM showing potential HSS enhancement later in period. Considered poor steer as lacking CME enhancement Days 1-2.**

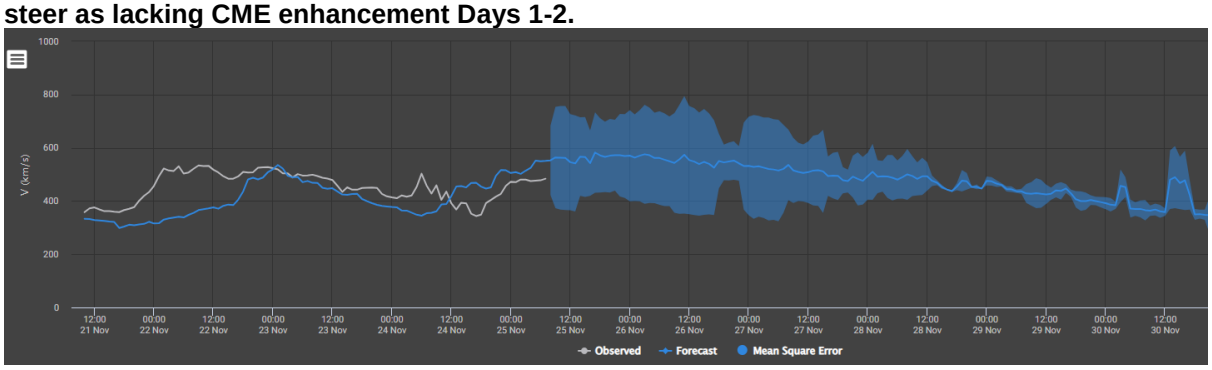
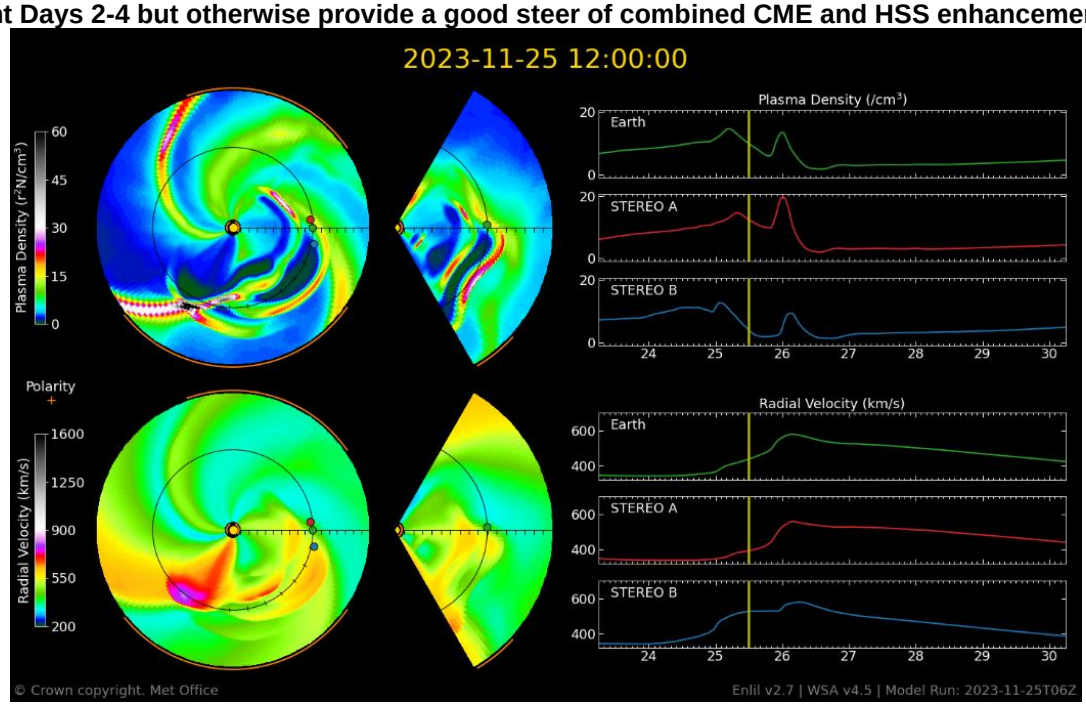



**Figure 4: MOSWOC Enlil showing CME arrivals Days 1-2 (25-26 Nov). Speeds may be slightly deficient Days 2-4 but otherwise provide a good steer of combined CME and HSS enhancements.**

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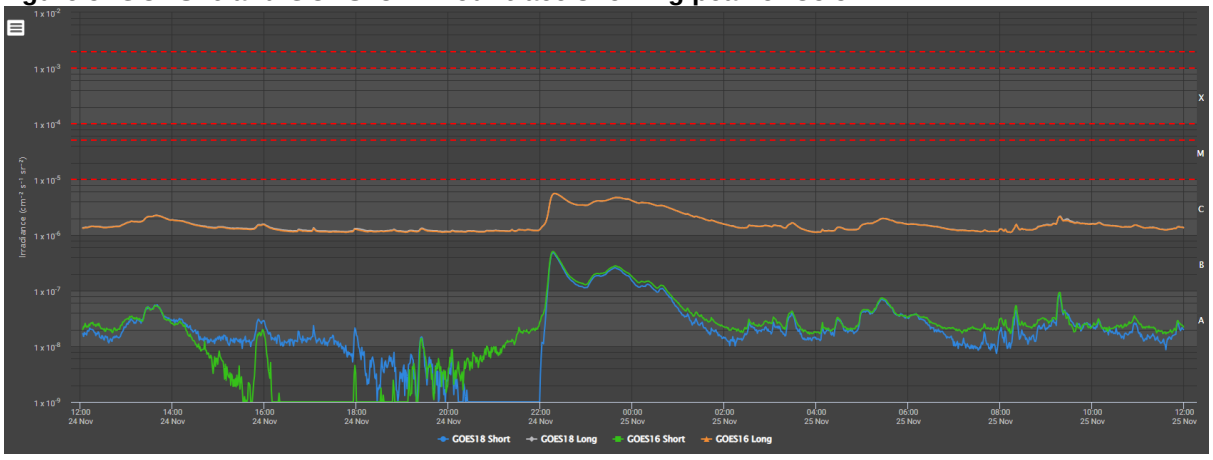
**Radio Blackouts - X-Ray Flares:**

There are currently twelve sunspot groups on the visible disc. Near centre disc in the northern hemisphere there is a cluster of four sunspot regions that appear to be contained within the same area of plage and magnetically connected. AR3490 (Dac/Beta-Gamma) was responsible for the largest flare in the period, a C5.5 at 24/2219 UTC. Since then, it has seen slight decay with the loss of a delta spot and the splitting and spreading of its largest spot. AR3492 (Chi/Beta) is the largest group within the region and consists of two large unipolar spots and a trail of faint spots of opposite polarity that extend to the east, with the group weakly bipolar as a result.
The largest group on the disc is AR3500 (Dkc/Beta-Gamma-Delta) in the southeast. This compact region is dominated by one large delta spot in its central portion and a number of other mature spots in close proximity. AR3499 (Dai/Beta) in the southwest was responsible for the M1.1 flare on 24/0933 UTC. This region continues to show some slight signs of growth and increase in complexity.

The aforementioned regions contribute the majority of the flare risk on the disc at present, with the remaining groups smaller and more magnetically simple at this time.
AR3498 will rotate over the western horizon on Day 2 (26 Nov). However, bright areas on SDO imagery and occasional CME activity just beyond the eastern limb suggests the presence of further active regions that are expected to rotate onto the visible disc by Day 4 (28 Nov). As a result, flare probabilities have been maintained at saturated levels. Activity is expected to increase to Moderate, with further isolated M-class flares, and a slight chance of an isolated X-class flare.

| X Ray Flares | Level | Past 24 Hours (Yes/No) | Day 1 (00-24 UTC) | Day 2 (00-24 UTC) | Day 3 (00-24 UTC) | Day 4 (00-24 UTC) |
|---|---|---|---|---|---|---|
| Probability | | | (%) | (%) | (%) | (%) |
| Active | R1-R2 M Class | No | 70 | 70 | 70 | 70 |
| Very Active | R3 to R5 X Class | No | 10 | 10 | 10 | 10 |

**Figure 5: GOES16 and GOES18 24 hour trace showing peak of C5.5.**

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## Solar Radiation Storms - (High Energy Protons):

The high energy (greater than 10MeV) proton flux observed by GOES16 is currently at Background levels.

There are several moderately-large and fairly complex regions close to the centre of the disc in the northern hemisphere. These result in a slightly above background risk of an S1/Minor Solar Radiation Storm in the coming days. This risk remains small, but with a minor uptick in probabilities later in the period when these groups move into a more favourable location for connection with Earth, as they move further into the western solar hemisphere, apparent from Earth.

| Radiation Storms Probability (Exceedance) | Level ($cm^{-2}$ $sr^{-1}$ $s^{-1}$) | Past 24 Hours (Yes/No) | Day 1 (00-24 UTC) (%) | Day 2 (00-24 UTC) (%) | Day 3 (00-24 UTC) (%) | Day 4 (00-24 UTC) (%) |
|---|---|---|---|---|---|---|
| **Active** | **≥ S1** | No | 10 | 10 | 15 | 15 |
| **Very Active** | **≥ S3 *** | No | 1 | 1 | 1 | 1 |
| * S3 ≥ 10 MeV ≥ 1000 pfu and / or ≥ 50 MeV ≥ 10 pfu. (pfu = $cm^{-2}sr^{-1}s^{-1}$) | | | | | | |

## High Energy Electrons Event (≥ 2MeV):

Electron flux levels fell to Background levels following the arrival of the CME from early 22 Nov at L1. This suppression in electron flux is expected to persist for much of the forecast period, given combined forecast CME and HSS (CH75/+) influences on the electron belt and geomagnetic activity in the coming days. High levels of election flux may be reached Day 4 (28 Nov) when there is an increasing chance that the reduction in the solar wind pressure following recent CMEs and high-speed streams could allow the Van Allen belts to relax and electron flux at L1 to subsequently increase. However, this also relies on possible glancing blow CME on Day 3 missing Earth.

Fluence levels are expected to remain below the 1e8 Active threshold throughout the period. The Met Office REFM model forecast will not account for the recently observed nor the forecast CME arrivals, therefore will likely indicate higher fluence values than should be observed. A rising trend in the Recurrence forecast between Days 1 and 3 (25-27 Nov) is based on an earlier arrival time of the high-speed stream from CH75/+ and subsequent recovery of the electron belts on the previous solar rotation. Any notable rise is not expected to take place until Day 4 (28 Nov) or later, beyond the forecast period.

| GEO Electron Environment Probability (Exceedance) | Level ($cm^{-2}$ $sr^{-1}$ $day^{-1}$) | Past 24 Hours (Yes/No) | Day 1 (00-24 UTC) (%) | Day 2 (00-24 UTC) (%) | Day 3 (00-24 UTC) (%) | Day 4 (00-24 UTC) (%) |
|---|---|---|---|---|---|---|
| **Active** | **≥ 2 MeV ≥ $1x10^8$** | No | 1 | 1 | 1 | 5 |
| **Very Active** | **≥ 2 MeV ≥ $1x10^9$** | No | 1 | 1 | 1 | 1 |

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**Figure 6: GOES16 24 hour electron trace showing drop off following CME arrival**

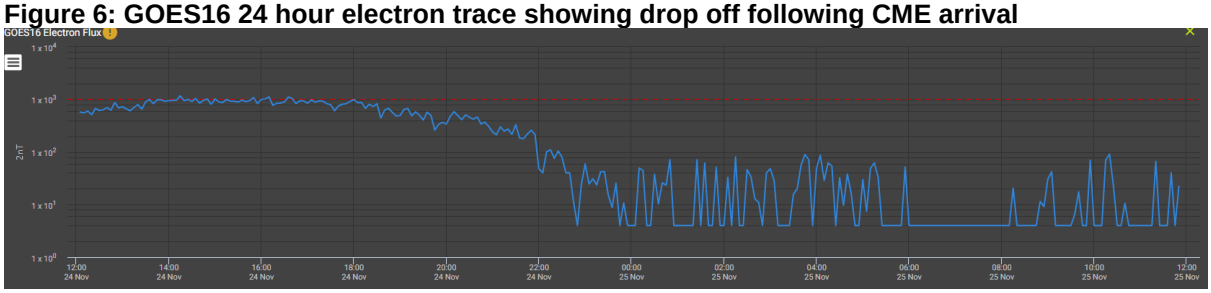
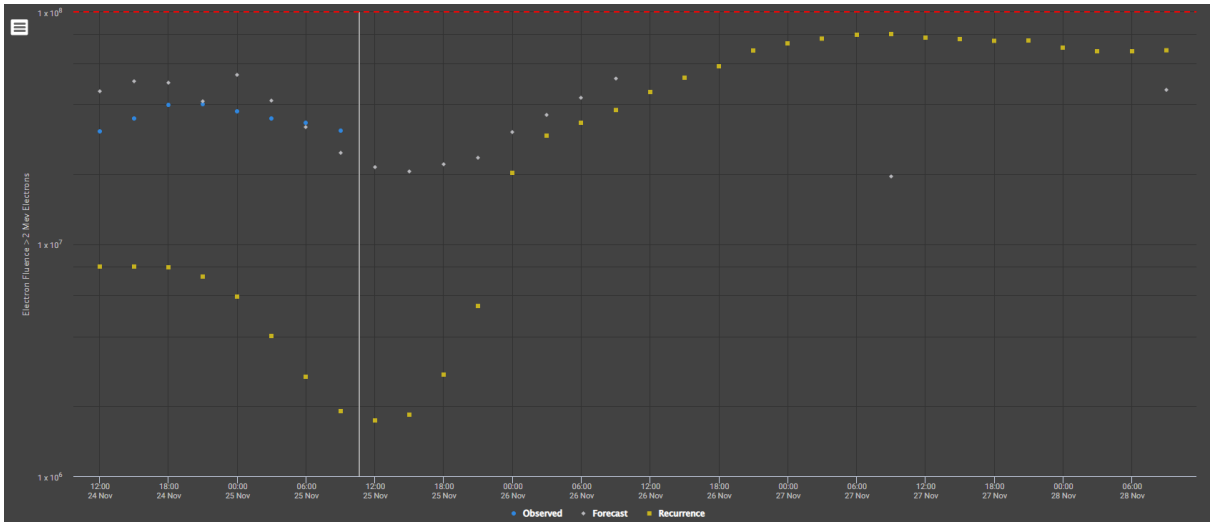



**Figure 7: MOSWOC REFM considered to be giving a poor steer given complicated geomagnetic forecast.**

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